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FULL SCALE TESTING OF HIGHWAY BRIDGE RAILS AND MEDIAN BARRIERS

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FULL SCALE TESTING OF HIGHWAY BRIDGE RAILS AND MEDIAN BARRIERS

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SYNOPSIS

Full scale dynamic tests were made of fifteen designs of traffic barriers for use in highway medians (center strips). The object of this series of tests was to develop efficient barriers for use in freeway construction. A new barrier design was developed as previously reported (Reference 1), and several installations are now in place on California highways and are proposed elsewhere.

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* * * * * * * * * *

I. INTRODUCTION

The advent of the divided expressway and freeway has reduced the frequency of deadly head-on collisions that are so prevalent on the undivided type of highway. Unfortunately, this type of accident has not been eliminated entirely on the divided highway in that occasionally an out-of-control car will pass over even a wide median between the opposing roadways and may be involved in a head-on collision in the opposite roadway. Such collisions usually result in the death or serious injury of the majority of the occupants of both cars. As outlined in a report by the California Division of Highways (Reference 2) 20% of the fatal accidents that occur on freeways are the result of cross-median accidents.

It is the purpose of this report to present the detailed results of a selected group of tests which typify collisions with three different classifications of highway median barriers which are used to prevent cross-median accidents. A general criteria is outlined for each of these specific classifications.

The four tests reported in this study have been selected from thirty tests made of fifteen median barrier designs and seven highway bridge rail designs. These tests were performed during an over-all study on both highway medians and bridge rails. The bridge rail study has been only partially reported (Reference 3) while the barrier study has been completely reported (Reference 1) to the Highway Research Board in January 1960. As a result of this latter study two barrier systems were developed and are now being used in the median barrier program of the Division of Highways.

All the preliminary tests were conducted by driving a medium weight 4-passenger sedan automobile into the various test barriers at a speed of approximately 60 mph and an angle of collision of 30°. This same weight of car, speed and approach angle were used during all tests to obtain as good a comparison as possible between the various designs. Final tests were made on the two designs, which were judged to be the most efficient after the preliminary program, by resultant vehicular deceleration sustained during a heavy oblique collision with a flexible barrier will be of relatively low magnitude in both the longitudinal and transverse axis, the decelerations being slightly higher in the longitudinal than in the transverse axis. This type of barrier is illustrated by Fig. 4.

III. DATA REDUCTION METHODS

Reduction and comparison of data from thirty tests in the median barrier and bridge rail collision series was simplified because the approach angle of 30° oblique to the barrier and the impact speed of 60 mph was held constant.

Throughout this study, the kinematics of the dummy and the deceleration measurements were considered only of secondary importance since the principal objectives were limited to the rail-vehicle reaction during a collision, and the post collision trajectory of the vehicle. Therefore, instrumentation of the vehicle and dummy was limited to the minimum that would give a relative indication of injuries a human might encounter during a collision with each of the barrier types. Further collision studies of this type would necessarily include a more highly instrumented vehicle and dummy to facilitate a precise evaluation of an injury producing collision.

In general, the vehicle damage and dummy injuries were the same for similar types of barriers but varied with different types. This report covers four tests selected so as to illustrate these differences. The first three tests (Figs. 2, 3, and 4) are used to outline these differences, whereas the fourth (Fig. 5) is used to illustrate the more abrupt collision resulting from trapping the vehicle.

The basic data presented in this report were derived from analysis of the individual frames from high speed cine film. Supporting data on the deceleration of the dummy were derived from electrical accelerometers and post collision analysis.

The inferred injuries tabulated on the data sheets were evaluated from visible evidence of cuts, tears, and punctures on the dummy and deformation of the door, steering wheel, windshield, dash, and header. No scientific medical analysis of the dummy injuries was made because an evaluation of this nature was considered beyond the scope of this study.

IV. INSTRUMENTATION

A. Collision Vehicles

The vehicles used for this 1959 Test Series were standard 4-door Chevrolet or Ford sedans, 1951 to 1955 models, supplemented by one 34-passenger 17,000 lb bus. The center of gravity of the various passenger cars was reported to be between 21 in. and 23 in. above the pavement. The average height of the vehicles with dummy and instrumentation was 4,000 lb. The rear seat cushion and spare tire were removed to facilitate installation of the control instruments. The following modifications and installations were made in the test vehicles (Figs. 6 and 7).

1. A Bendix Hydrovac booster was attached to the master brake cylinder for radio remote operation of the brakes.

the dummy indicate the severity of injury producing collisions as well as the general body areas injured on impact with the door or steering column of the crash vehicle, and can in most tests be considered the maximum Gs deceleration sustained during impact.

These decelerations were transmitted through a 300 ft tether line connected from the accelerometers in the collision vehicle to the recording equipment in an instrument truck. The instrument truck followed parallel to and 30 to 50 ft behind the collision vehicle on the approach path. During two tests the tether line was severed a few milli-seconds after impact; however, complete dummy deceleration data were obtained on most of the runs. To supplement the accelerometer data, the movements of the dummy under collision conditions were recorded by the high speed tower camera on the first seven tests.

In addition to the above decelerometers, two unbonded uni-axial strain gage type accelerometers were mounted on the right side of each vehicle frame at Station 10 (10 ft to rear of front bumper) for comparison to studies by others (Reference 4). Unfortunately, the prime objective of this study demanded completion at such an early date that insufficient time was available to properly calibrate or dampen these accelerometers. The data from this instrumentation, therefore, is not considered sufficiently reliable for report presentation and is not included.

The following is a list of acceleration equipment used during the test program:

Crash Vehicle: Two Statham Mod. A5a-200-350$\pm$200G accelerometers. Natural frequency 850 cps. Silicone fluid dampened to 570 cps. Mounted on right side of vehicle frame at Station 10.

Two Statham Mod. A5a-25-350$\pm$25G accelerometers. Natural frequency 375 cps. Silicone fluid dampened to 262 cps. Mounted in chest cavity of anthropometric dummy.

One Weston photocell Mod. No. 594 RR for event marker.

Instrument Truck: One 4 channel Consolidated Electrodynamic Corp. Bridge Balance Mod. No. 8-108.

One 4 channel Video Instruments Co., Inc. D.C. Amplifier, Model No. 71.

One Heiland 12 channel recording oscillograph Mod. A301R-12.

One 200 cps time base oscillator for oscillograph time lines.

The top of the vehicle from the windshield to 6 in. behind the driver's seat was cut away to allow total photographic coverage of the dummy reaction from the overhead camera. It was concluded after an analysis of the data film records of these first seven tests that the kinematic pattern of the dummy movement was very similar for all oblique collisions with semi-rigid barriers.

Additional data of this type was not considered to be of enough significance to justify removal of the vehicle top on subsequent tests.

top of each test data sheet are reproductions of the most significant frames from this sequence camera coverage.

Listed below is a description of the data and documentary cameras:

Camera Number	Type	Frames /Sec.	Lens	Film	Location	Function
1	Fastax	1200	12.5mm	16mm, 100' roll	Tower	Data
2	Gordent 200	200	13mm	16mm, 100' mag.	Tower	Data
3	Gordent 200	200	4 in.	16mm, 100' mag.	Front Turret	Data
4	Gordent 200	200	4 in.	16mm, 100' mag.	Rear	Data
5	Hulcher 70	20	6.5 in.	70mm, 100' roll	Rear Platform	Doc. Sequence
6	Bolex 16	64	Zoomar	16mm, 100' roll	Various	Doc. Pan
7	Bell & Howell	64	1 in.	16mm, 100' roll	Various	Doc. Pan
8	G.S.A.P.	64	1 in.	16mm, 50' mag.	Various	Doc.

As each type camera motor required a different time interval to reach operating speed and each camera had a different operating frame speed, it was necessary to control them manually and in sequence from the camera control center.

A typical sequence for camera and flash bulb operation follows:

Impact minus 3 seconds, camera #8

Impact minus 2 seconds, cameras #2, 3, 4

Impact minus 1 second, camera #1

Impact minus 200 millisecond, flash bulb #4

For certain barrier tests additional data cameras were positioned at strategic points to cover wheel or front suspension reaction, post and rail reaction.

For a closer view of the dummy reaction during the two bus tests (Reference 1), a 200 fps data camera was rigidly mounted above the rear window of the collision vehicle to record a full kinematic study of dummy reaction. This camera was connected to a ten second time delay relay starting the camera when the collision vehicle was within 10 seconds of impact. A spring loaded micro-switch mounted on the rear bumper actuated the time delay relay when the power assist truck released the collision vehicle on the collision path.

As data camera #1 was the only camera with 1000 cycle timing pips, it was necessary to provide a method of timing the other data cameras. A segmented drum revolving at approximately 1600 revolutions per minute was mounted directly below the tower in view of all data cameras. Analysis of the revolving drum image driving a 34-passenger bus into collision with the barriers at 40 mph and an angle of 30°. (The bus at 40 mph represented slightly more than twice the kinetic energy developed by the cars at 60 mph.) One collision with a passenger car was made at a 20° angle of approach to determine the effect of a flat angle on contact.

The 60 mph speed and the 30° angle of approach combination was selected as representative of the more severe type of possible oblique collision with a median barrier. (The primary aim in this study was to test the resistance and reaction of the barrier.) This speed and angle was selected after studying the results of many actual cross-median accidents as well as analyzing this department's past experience with several different speeds and angles of approach used during the testing of bridge curbs and rails reported previously (Reference 3).

Movements of the vehicle and barrier at the time of collision were recorded by a series of high and normal speed cameras placed approximately as shown on the typical test site layout diagram (Fig. 1). Dynamic data was reduced from the film. These data were supplemented by deceleration recordings taken from accelerometers located in an anthropometric dummy restrained by a seat belt and located in the driver's seat of the test car. In addition to this all physical changes in dimensions and condition of the barrier system were listed as well as the observations and appraisals of damage to the car and visual action during and after the collision as recorded by trained observers at the site.

II. BARRIER CRITERIA

A highway median traffic barrier is designed to retain a colliding motor vehicle on the originating side of roadway centerline. Such barriers may be classified as follows:

RIGID BARRIER

A barrier that exhibits little or no deflection under the condition of oblique collision loading is defined as a rigid barrier. The resultant vehicular decelerations sustained during a heavy oblique collision with a rigid barrier will be relatively low in the longitudinal axis (with possible high peaks for very short durations), while the decelerations in the transverse axis will be relatively high and of significant duration. This type of barrier is illustrated by Fig. 2.

SEMI-RIGID BARRIER

A barrier that deflects appreciably but within limits so as to form a smooth "pocket" under the condition of oblique collision loading is defined as a semi-rigid barrier. The resultant vehicular decelerations sustained during a heavy oblique collision with a semi-rigid barrier will be moderately high in both longitudinal and transverse axis and of appreciable duration, the decelerations being slightly higher in the transverse than in the longitudinal axis. This type of barrier is illustrated by Fig. 3.

FLEXIBLE BARRIER

A barrier that deflects considerably and gradually slows a vehicle under the condition of oblique collision loading is defined as a flexible barrier. The

2. The ignition system was bypassed and wired into the remote-radio control panel.

3. The gas tank was drained and the gas line rerouted into a 1-gallon tank mounted over the spare tire well. This tank was equipped with a relief valve and cut-off valve to prevent leakage of fuel when the vehicle rolled.

4. A mounting plate was welded to the floorboard in the front seat compartment for installation of the steering motor.

5. Storage batteries and the steering pulser were bolted to the rear seat floorboard.

6. The remote radio-control equipment was bolted to the trunk compartment deck (see Fig. 7). Whip antennae were mounted on the rear of the vehicle.

7. A seat belt was installed on the driver's side.

8. An adjustable pulley was clamped to the steering wheel for control of the vehicle through the battery driven steering motor. Approximately 2 man days' labor were required to modify each stock passenger vehicle to radio control.

Radio control of the vehicle along the 2,000 ft collision path was accomplished by means of 3 modulated tones and the R.F. carrier from a crystal controlled transmitter on 27.255 megacycles (citizens band) installed in the control truck (see Fig. 7).

The five basic functions considered necessary for complete and flexible control of the test vehicles were: ignition on, ignition off, steer right, steer left, and brakes on. The accelerator linkage was wired in the full throttle position before push off. A nitro-methane gasoline mix was used in those vehicles that could not normally attain the required 60 mph in the 2,000 ft course. Speed trials determined the starting position on the course for vehicles that exceeded the required terminal speed. The average recorded speed was between 58 and 62 mph at impact for all high speed tests.

An ignition system switch was energized through a relay controlled by the R.F. carrier from the control truck transmitter. A failure in any of the radio control equipment opened the ignition relay and allowed the car to stop under compression.

A signal to the steering motor pulser actuated the steering motor in incremental steps, variable in each direction from 1/8 in. to 1 in. per pulse. The rate was variable from 20 to 20 pulses per second. The steering pulser was set after determining the amount of correction necessary to the steering of each vehicle by several trials before the actual test.

B. Deceleration Instrumentation

A Sierra Engineering Company, Model 157, 6 ft 0 in. - 220 lb anthropometric dummy positioned in the driver's seat was restrained by a conventional lap belt. The dummy was instrumented with two accelerometers mounted in the chest cavity in the relative position of the heart, with the axes sensitive to the longitudinal and transverse deceleration of the upper torso. Deceleration readings from

In all semi-rigid and rigid barrier tests where the vehicle was not trapped by the posts, the dummy was subjected to high transverse decelerations. It was forced against the left door with sufficient pressure to break the latching mechanism. In tests where relatively high transverse decelerations were sustained after the vehicle left the barrier, the dummy probably would have been ejected from the vehicle had it not been restrained with a lap belt as the door usually flew open. However, in cases where the dummy was in contact with the door and the door in turn was against the barrier throughout the period of transverse G loading, (as exemplified by the tests on the blocked-out barrier, Fig. 3), the rail prevented the door from opening.

An examination of the sequence photographs of Test No. 22 (Fig. 2) reveals that the rail retained only the lower part of the door and allowed the top of the door to be forced open as much as one foot. In cases where the head of the dummy protruded from the vehicle, skull injuries usually resulted.

When the dummy experienced excessive longitudinal decelerations, such as in Test No. 18 (Fig. 5), the dummy was thrown forward and the the left, striking the chest violently against the steering wheel and column, the skull impacting the header area. This action was typical of all tests where the front wheel assembly was trapped by the posts. A detailed analysis of steering wheel deformation with related injuries was not attempted due to the resistance offered the steering wheel by the remote steering pulley bracket.

Dummy deceleration data from all tests of cable-chain link (Fig. 4) barriers show very low transverse decelerations (2-9 Gs) and low longitudinal decelerations (3-7 Gs). If the dummy did impart a loading great enough to spring the door latching mechanism, the door did not open because the vehicle was firmly against the upper cables when peak transverse decelerations occurred.

C. Photographic

Experience on previous collision tests by this department have shown that photographic coverage of an event will yield the maximum of significant data for the lowest initial investment. As it was necessary that the final analyis and presentation be in the form of a film report in addition to a written report, the data cameras had to also function as documentary cameras. A frame rate of 1200 ft per second was used for the tower mounted camera (Fig. 8) to record information on impact velocity, approach angle, and average vehicle deceleration. The field of view from this camera was 30 ft x 40 ft covering from 20 ft before impact to 20 ft beyond impact parallel to the rail. To provide documentary coverage, a 200 frame per second camera with the same field of view was mounted adjacent to the data camera. The field of view from this second camera covered from 10 ft behind to 30 ft beyond impact parallel to the rail.

Due to the variable post collision trajectories of the test vehicles, it was found necessary to orient all but the tower mounted data cameras at different locations for each test. The relative location of the cameras, barrier, collision vehicles, control and instrument vehicles for a typical test are shown on Fig. 1. This was varied to meet the expected reflection action of each test. Standard photographic coverage of each collision included: one turret-mounted front data camera, one rear data camera, two overhead data cameras, and two documentary cameras panning the vehicle through collision to the terminal point. In addition to the above photographic coverage, a 70 mm sequence camera operating at 20 frames per second was used to record a documentary series that could be enlarged and analyzed for details. The pictures exhibited at the and the timing pips on the film from camera #1 provided a time-in-space correlation for all data cameras. It was thus possible to correlate the information from any film frame on the data cameras with the film from the #1 camera.

Two pressure sensitive electrical switches were mounted on the pavement on the collision path and positioned 5 ft and 15 ft before the collision point (Fig. 8). As the vehicle passed over the switches, flash bulbs positioned behind the barrier in view of the high speed overhead data camera were fired. By analysis of the flash bulb images and the 1000 cycle timing pips on the high speed data film from camera #1, the average speed of the test vehicle 10 ft before impact was determined.

A third flash bulb mounted on the collision vehicle was fired on impact by a "G" switch set to close when the deceleration approached 2 "G". A photocell mounted adjacent to the flash bulb transmitted this event marker pulse to the instrument truck accelerometer recorder through the tether line and onto the oscillograph recorder film. This pulse provided a correlation pip between the high speed data camera and the deceleration recordings.

When strain gages were mounted on the barrier rails to measure the transmission of stress through the rail members, it was possible to correlate the stress recording oscillograph to the data cameras through a similar flash bulb/photocell unit positioned behind the barrier and in view of data camera #1. This flash bulb was triggered manually from the camera control center a few milliseconds prior to impact. This report does not contain the complete stress and strain information. This data was used merely to verify existing specification requirements for the strength at the bolted joints in the steel beam members.

The testing techniques involving remote control of cars driven into collision with the various types of barriers, photographic recording of the crashes, and accelerometer readings representing the reaction of vehicle and passenger all combined to develop a satisfactory conclusion to this project.

To date 50,000 ft of cable-chain link barrier and 40,000 ft of blocked-out metal beam barrier have been installed and have been open to traffic an average of about five months. During this time 32 accidents have been reported by the highway patrol and property damage of the barriers indicate innumerable other minor accidents. Two fatalities occurred as a result of the 32 accidents. Since these reported accidents were all of the high speed severe type, it can safely be assumed that any one of these accidents could have resulted in one or more fatalities or serious injury if the barrier had not been present or had been of improper design.

One year after completion of the projects a complete accident study will be performed so as to accurately evaluate the worth of this barrier program.

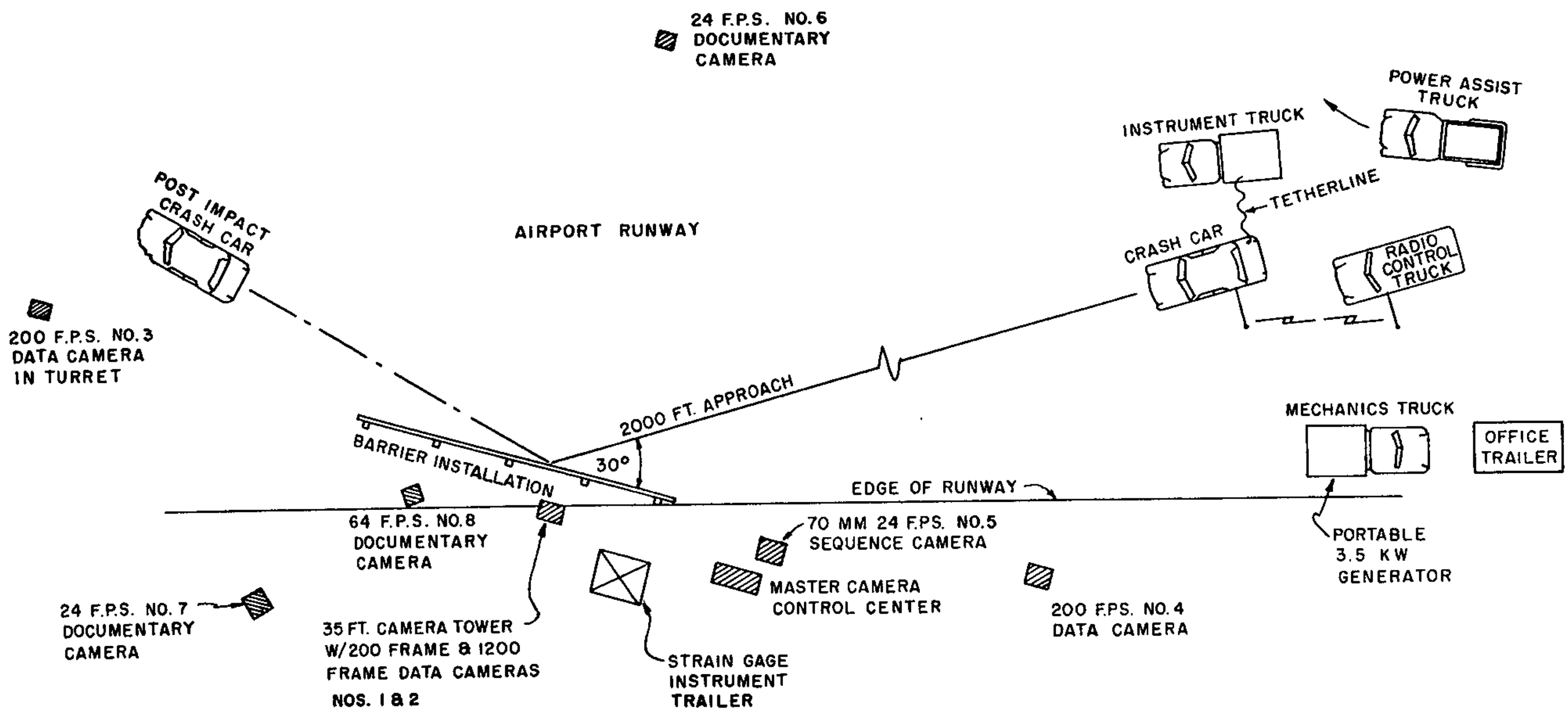
V. REFERENCES

1. Dynamic Full Scale Tests of Median Barriers, J. L. Beaton and R. N. Field, 39th Annual Meeting, Highway Research Board.

2. Median Accident Study (1958), Traffic Department, California Division of Highways.

3. Full Scale Tests of Concrete Bridge Rails Subjected to Automobile Impacts, J. L. Beaton, Vol. 35, Highway Research Board Proceedings.

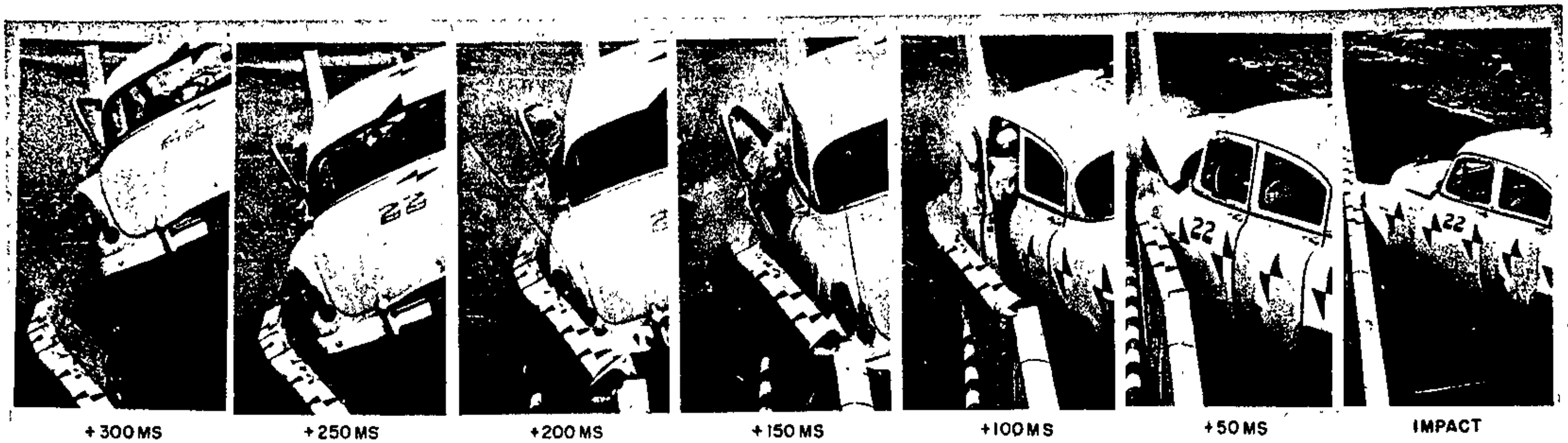
4. Technical Findings from Automobile Impact Studies, D. M. Severy and J. H. Mathewson, SAE Annual Meeting, January 1956.

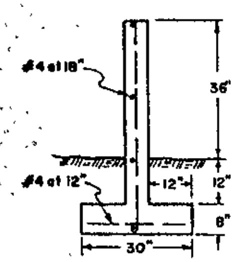


PLAN VIEW OF TEST SITE

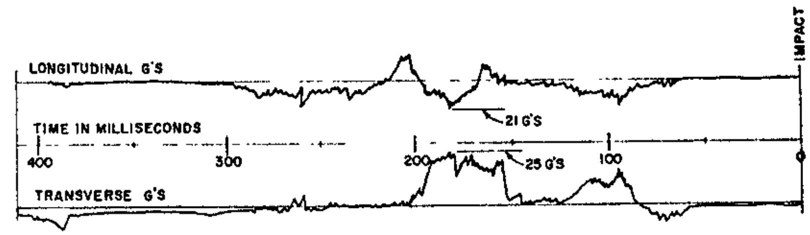
STATE OF CALIFORNIA DIVISION OF HIGHWAYS MATERIALS & RESEARCH DEPT.

FIG. 1



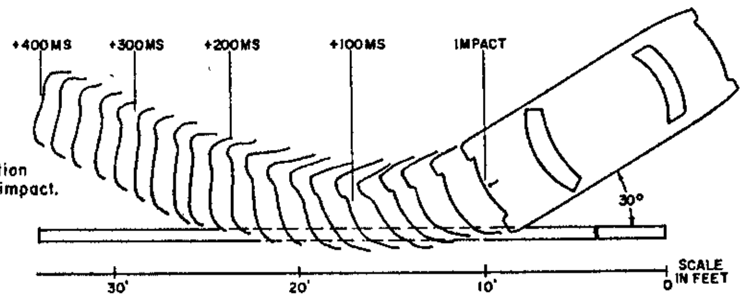


GUARDRAIL . . . . 36" Conc Wall
6" Thick
REINFORCING BAR SPACING . . Vert. #4 at 12"
Horiz. #4 at 18"
LENGTH OF INSTALLATION . . 85'
GROUND CONDITION . . . . . Wet
PAVEMENT CONDITION . . . . Dry

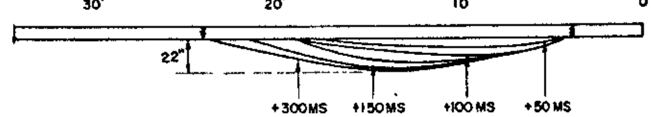


DUMMY DECELERATION PATTERN

Final Position 124' from impact. After one roll over.



VEHICLE DEFLECTION PATTERN



RAIL DEFLECTION PATTERN

DUMMY INJURY . . . . Concussion, severe shoulder & chest injuries
GUARDRAIL DAMAGE . . . . 20' Wall broken
VEHICLE DAMAGE . . . . Beyond economic repair.
MAX. DYNAMIC DEFLECTION OF RAIL . . 22"
TIME FROM IMPACT TO STOP . . . . . 3000 Milliseconds.

TEST NO. 22
DATE 8-30-59
VEHICLE . . . . Chev. 54 Sedan
SPEED . . . . 61 MPH
IMPACT ANGLE . . . 30°
VEHICLE WEIGHT . . 3850
(W/DUMMY & INSTRUMENTATION)

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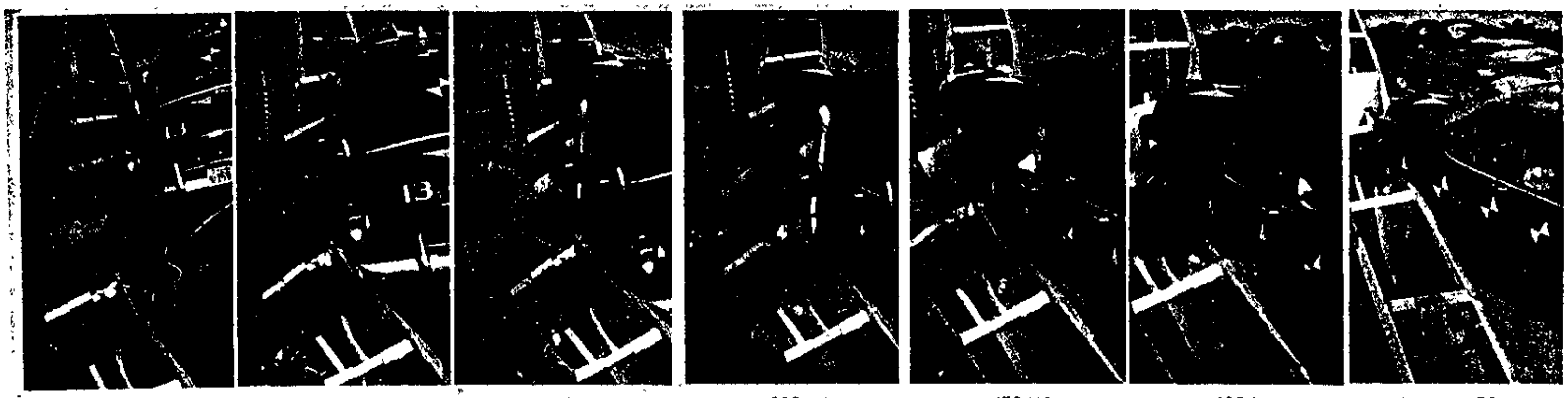
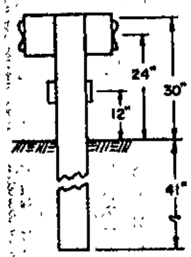
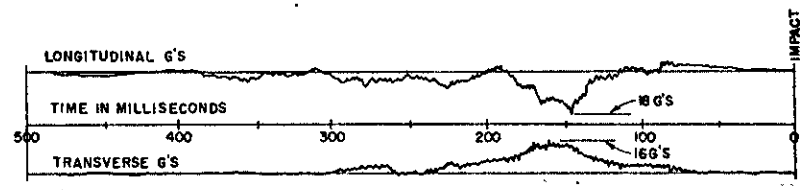
FIG. 2

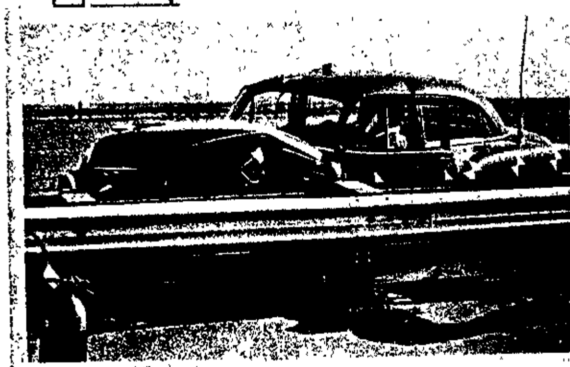




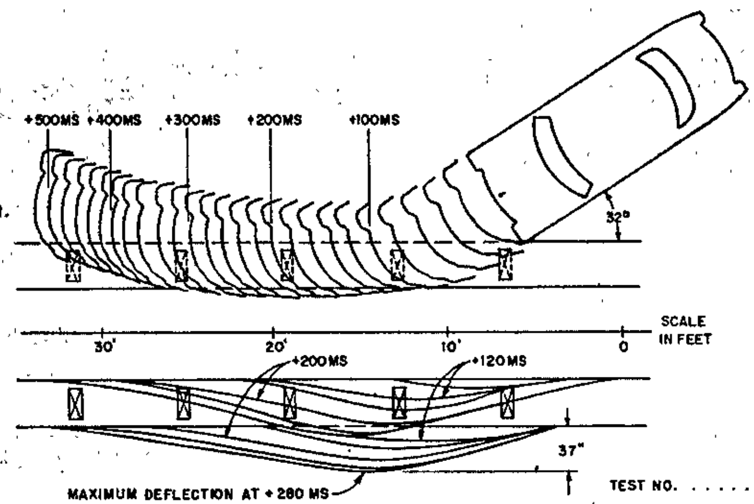
GUARDRAIL . . . . W Section
CHANNEL . . . . 6" ⊓ 8.2#
BRACKET . . . . 8x8x14 D.F. Block
POST . . . . 8x8 D.F.
POST SPACING . . . . 6'-3" O.C.
LENGTH OF INSTALLATION . . 125'
GROUND CONDITION . . . . . Dry
PAVEMENT CONDITION . . . . Dry



DUMMY DECELERATION PATTERN



Final Position 94' from impact.



VEHICLE DEFLECTION PATTERN

RAIL DEFLECTION PATTERN

DUMMY INJURY . . . . Possible shoulder and head injuries.
GUARDRAIL DAMAGE . . . . 4 Sections damaged beyond repair.
CHANNEL DAMAGE . . . . 4 Sections damaged beyond repair.
POST DAMAGE . . . . 3 Posts damaged beyond repair.
VEHICLE DAMAGE . . . . $ 900
MAX. DYNAMIC DEFLECTION OF RAIL . . . . 37"
TIME FROM IMPACT TO STOP . . . . . 3100 Milliseconds.

TEST NO. 13
DATE 12-18-58
VEHICLE . . . . . Chev. 53 Sedan
SPEED . . . . . 60 MPH
IMPACT ANGLE . . 32°
VEHICLE WEIGHT . 4000
(W/DUMMY & INSTRUMENTATION)

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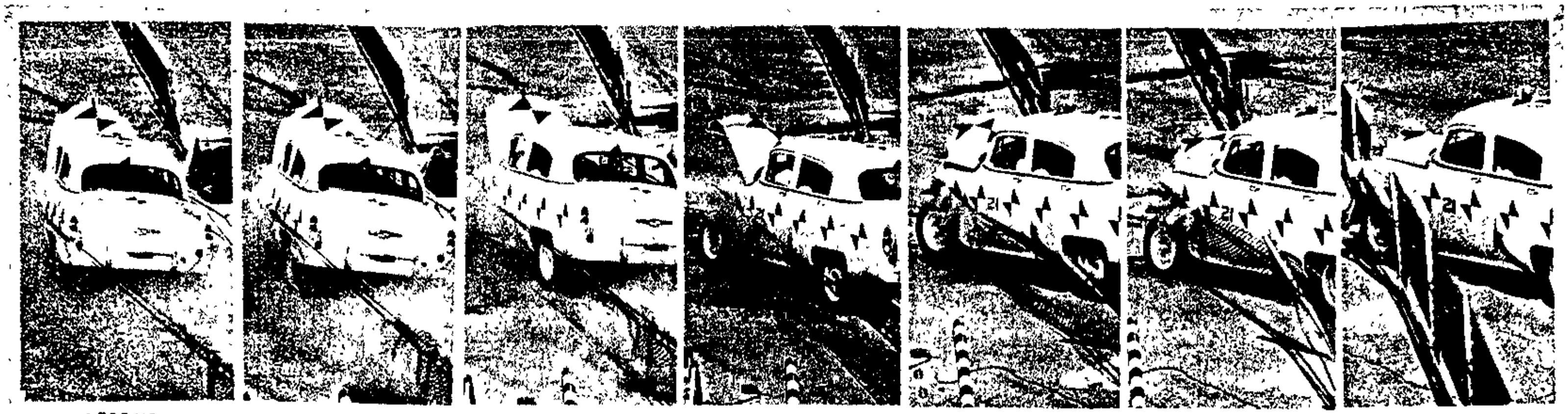
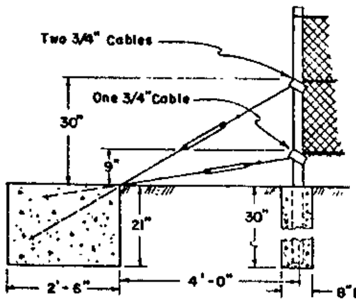
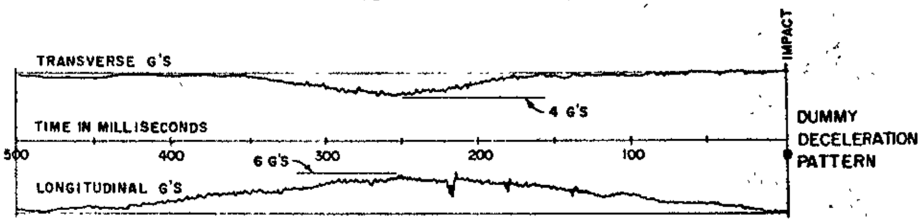
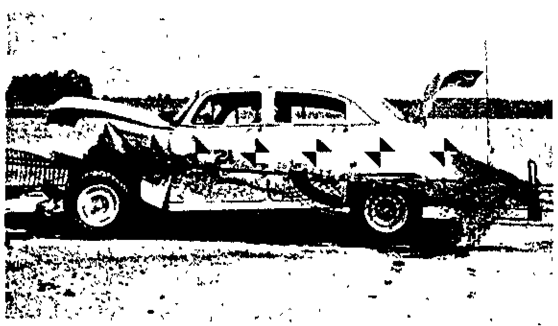
FIG. 3

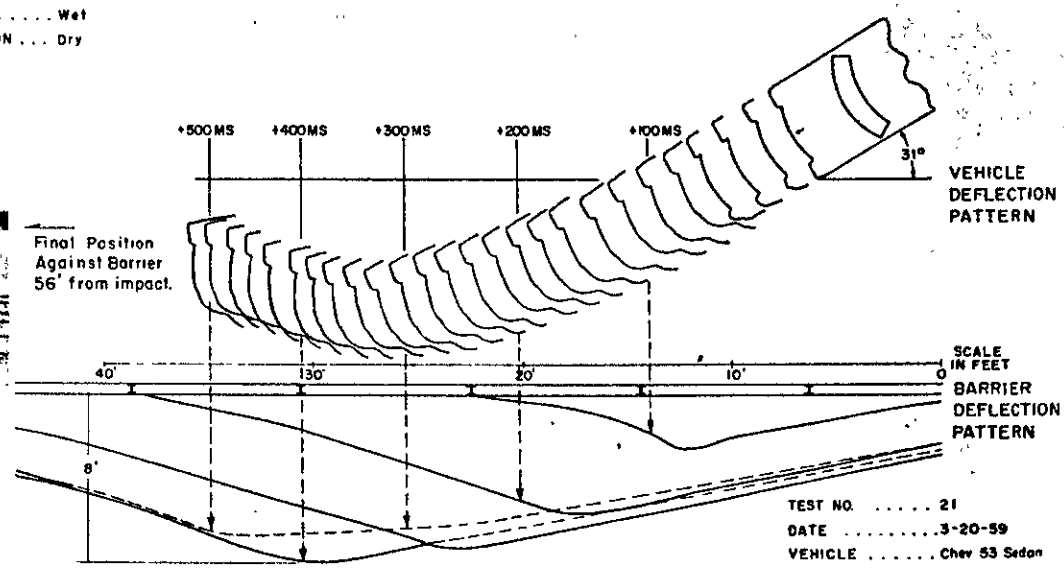




BARRIER . . . . . 36" Chain Link Fence W/ 3/4" cables 9" & 30" above pvmt.
POST . . . . 2 1/4"-4.1# H Section Fence Post
POST SPACING . . . . . 8' O. C.
LENGTH OF INSTALLATION . 600'
GROUND CONDITION . . . . . Wet
PAVEMENT CONDITION . . . Dry







DUMMY INJURY . . . . Minor scalp lacerations.
BARRIER DAMAGE . . . . 56' of fence knocked out.
No damage to cables.
POST DAMAGE . . . . 12 Posts damaged beyond repair.
VEHICLE DAMAGE . . . . Beyond economic repair.
MAX. DYNAMIC DEFLECTION OF CABLES . . 8'
TIME FROM IMPACT TO STOP . . . . . 1450 Milliseconds.

TEST NO. 21
DATE 3-20-59
VEHICLE . . . . . . Chev 53 Sedan
SPEED . . . . 60 MPH
IMPACT ANGLE . . . 31°
VEHICLE WEIGHT . . 3850
(W/DUMMY & INSTRUMENTATION)

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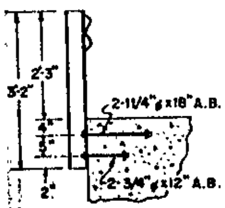
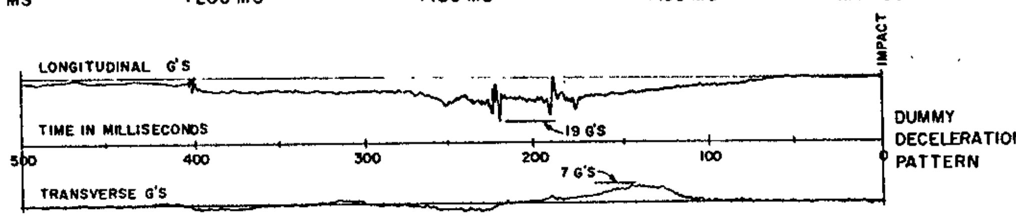
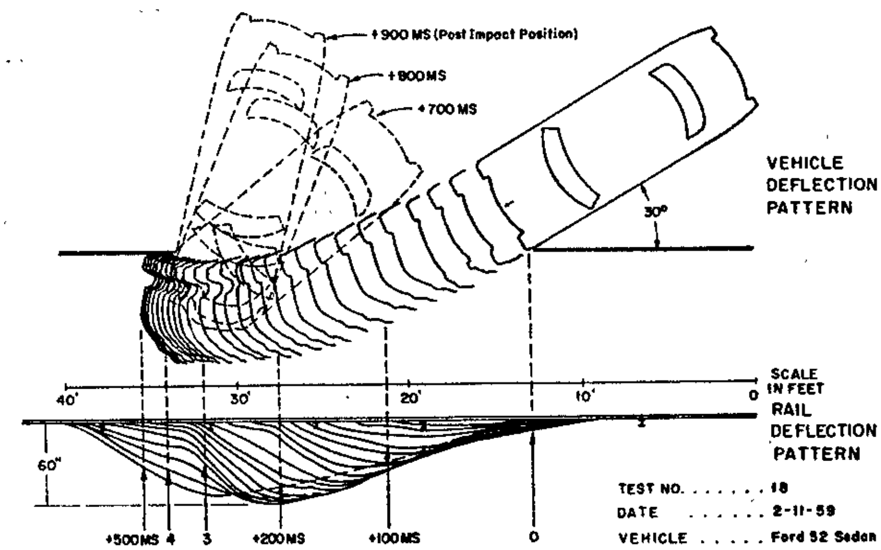
FIG. 4



BRIDGERAIL . . . . Single W Section
BRACKET . . . . None
POST . . . . 6" W" 15.5 #
POST SPACING . . . . . 6'-3" O.C.
LENGTH OF INSTALLATION . . 62.5'
GROUND CONDITION . . . . . Wet
PAVEMENT CONDITION . . . Damp



DUMMY INJURY . . . . Possible head & shoulder injuries.
BRIDGERAIL DAMAGE . . . . . . 3 Sections damaged beyond repair
POST DAMAGE . . . . 5 Posts damaged beyond repair.
VEHICLE DAMAGE . . . . Beyond economic repair.
MAX. DYNAMIC DEFLECTION OF RAIL . . 60"
TIME FROM IMPACT TO STOP . . . . 1050 Milliseconds.



TEST NO. 18
DATE 2-11-59
VEHICLE . . . . . Ford 52 Sedan
SPEED . . . . . . 55 MPH
IMPACT ANGLE . . . 30°
VEHICLE WEIGHT . . 4000
(W/DUMMY & INSTRUMENTATION)

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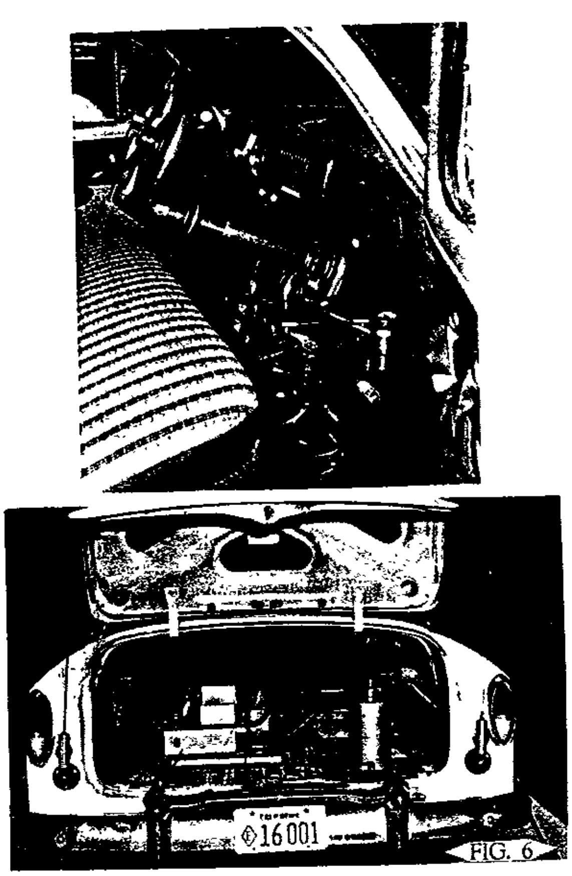
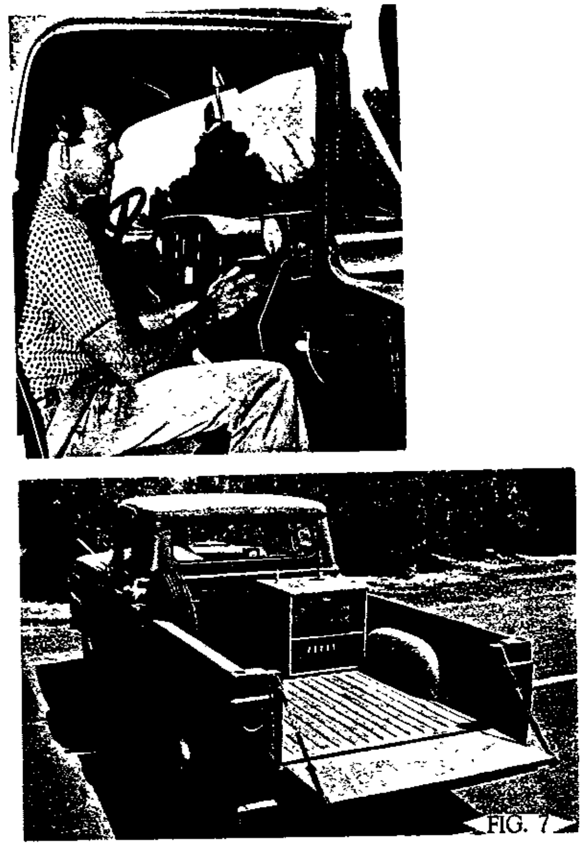
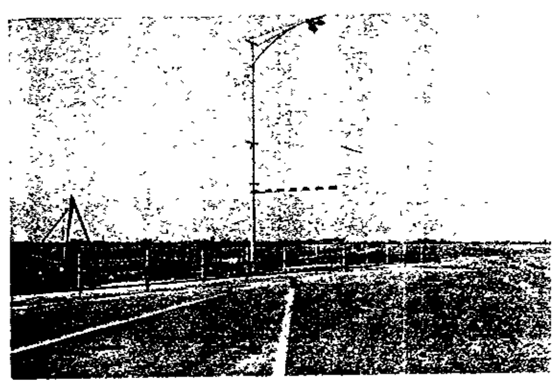
FIG. 5



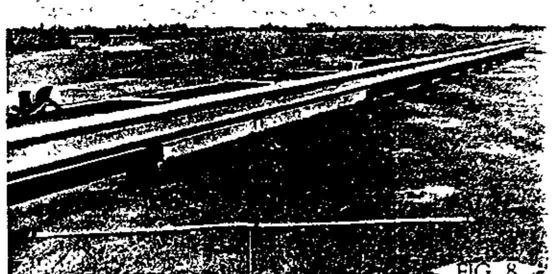
CRASH CAR RADIO CONTROL EQUIPMENT



CONTROL TRUCK RADIO TRANSMITTING EQUIPMENT



DATA CAMERA TOWER AS VIEWED FROM COLLISION PATH



POINT OF IMPACT ON BLOCKED-OUT BARRIER
CONTACT STRIP FOR DATA FLASH BULB IN FORGROUND